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DISCUSSION
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ISADORE NUSBAUM,[10] A.M. ASCE.—Technical literature is replete with

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investigations into the disposal of wastes in tidal waters, but no part of the field of sanitary engineering applied to liquid-waste disposal has less applicable knowledge. During the first half of the twentieth century there were extensive investigations in New York Harbor to determine the capacity of the harbor to receive municipal and industrial wastes, yet at the present time (1953) there is only little more published material on the subject despite the years and money expended on this project.

Since the centers of population on both the east and west coasts of the United States are located on tidal waters, these communities must dispose of sewage and industrial wastes into the tidal waters. The saline parts of the surface waters influenced by tidal movement have little or no use as a source of water supply for domestic and agricultural purposes. However, many economic, beneficial uses of great significance have been adversely affected by indiscriminate discharge into an apparently unlimited reservoir for disposal.

Before any adequate attack on the problem of tidal flushing of estuaries can be made, the estuaries must be classified in terms of the important factors that influence mixing and movement of water masses. D. W. Pritchard has presented an excellent review of several classifications.[11] One such classification

[11] "A Review of Our Present Knowledge of the Dynamics and Flushing of Estuaries," by D. W. Pritchard, *Technical Report No. IV*, Chesapeake Bay Inst., Johns Hopkins Univ., Baltimore, Md., March, 1952.

is in terms of fresh-water inflow and evaporation. A "positive" estuary is one in which there is a measurable dilution of sea water by land drainage. An "inverse" estuary has a mixture of high-salinity estuarine waters and sea water. In a third classification, neither fresh-water inflow nor evaporation dominates; this is known as a "neutral" estuary.

A classification scheme presented by Henry Stommel[12] is based on the

[12] "Recent Developments in the Study of Tidal Estuaries," by Henry Stommel, *Technical Report, Ref. No. 51-33*, Oceanographic Institution, Woods Hole, Mass.

predominant physical causes of movement and mixing of water in the estuary. Tide, wind, or river flow are indicated as the principal causes. In many cases no single cause of movement and mixing predominates. For example, in some estuaries the tidal motion will dominate near the channel connecting the estuary with the ocean, whereas well within the bay both wind and tide may contribute to the motion and the mixing. The classification of estuaries according to the type of tide which appears to influence the water movement leads to considerable misinterpretation of the forces effective in the little understood phenomena of flushing.

Studies by Mr. Pritchard,[13] J. P. Tully,[14] and Mr. Ketchum[15] have demonstrated that in the estuaries on the coastal plain of the Atlantic coast of the United States and the fiords on the western coast of Canada the predominant physical cause of mixing appears to be the tide. The principal reason for the movement of suspended and dissolved material out of the estuary is the inflow of fresh water. In the case of an inverse estuary, attempts have been made to obtain flushing parameters by the determination of a negative inflow of fresh water, or through the loss of fresh water by evaporation. The flushing problems of San Diego Bay (California) (essentially a neutral estuary) have not been successfully solved. In this bay, salinity determinations have been of little value since there is no significant difference between the saline content of the greatest part of the bay water and the surrounding ocean. In the extreme south end of the bay, which is very shallow, some increase in salinity is found during the summer months. There are no significant vertical salinity gradients in the bay. Under these and other circumstances, temperature gradients can have an important effect on the dynamic characteristics of the estuary. It has also been stated by Mr. Pritchard that in large estuaries the deflecting force of the earth's rotation may have an important effect on the distribution of salinity.

[13] "The Physical Structure, Circulation, and Mixing in a Coastal Plain Estuary," by D. W. Pritchard, *Technical Report No. III*, Chesapeake Bay Institute, Johns Hopkins Univ., Baltimore, Md., May, 1952.

[14] "Oceanography and Prediction of Pulp Mill Pollution," by John P. Tully, *Bulletin No. LXXXIII*, Fisheries Research Board of Canada, Ottawa, Ont., Canada, 1949.

[15] "The Exchange of Fresh and Salt Waters in Tidal Estuaries," by Bostwick H. Ketchum, *Journal of Marine Research*, Vol. X, No. 1, Sears Foundation, June 30, 1951, pp. 18–38.

The effects on the progressive wave caused by the reflection and resonance of waves have not been stressed by the authors. These factors are important, as are those changes which influence the progress of the tidal wave up an estuarial river. At several places along the Hudson River, between the mouth and Albany, N. Y., the tide and current tables for the Atlantic coast indicate tidal changes that are not merely frictional.

Standing waves such as those occurring in Long Island Sound (New York) can be considered as composed of two progressive waves—the incoming wave and the reflected wave—traveling in opposite directions. When the period of the reflected wave coincides with the period of the incoming wave, a standing wave is formed.

The designation of a third type of tidal wave form as the hydraulic type leads to some peculiar conclusions. The characterization of the flow in the Hudson River at Albany as being of the same type as that in the East River is not demonstrated by the data presented. Actually, H. A. Marmer described the tidal and current phenomena in the East River as caused by the "***interference of tide waves***" between that water entering the East River from Long Island Sound and that water entering the East River from the Upper Bay of New York Harbor.[16] This description made a nonmathematical discussion of the phenomena almost impossible and Mr. Marmer presented the following explanation based on the fact that high water and low water at each end of the East River occur at different times:

[16] "The Tide," by H. A. Marmer, D. Appleton and Co., New York, N. Y., 1926.

"***The movement of the water in East River is brought about by the fact that part of the time the level of the water in Upper Bay is higher than in Long Island Sound and part of the time it is lower. East River thus acts merely as a channel through which the water flows from the body having, temporarily, the higher level to the one having the lower level. In other words, the movement of the water in East River is primarily hydraulic in character.***"

Movement of water through the East River is thus "hydraulic" in both directions—and not at all similar to the flow occurring in the Hudson River.

Under the heading, "Derived Tides and Tidal Currents: Salinity Currents," it is stated that the fresh-water flow will tend to increase the duration and strength of the flood current. This is contrary to both theory and experience since the duration and strength of the ebb current are increased by the fresh-water flow because the accumulation of fresh water and tidal water at "flood" must find its way out on the ebb.

The attempt to explain (by the use of pressure diagrams) the fact that the net movement of the less saline water in the upper strata of the estuarine waters is seaward whereas the net movement of the deeper waters is upstream is not entirely adequate. Excellent discussions of this water movement have been given by Messrs. Pritchard,[13] Tully,[14] and Ketchum.[17] It has been

[17] "The Oceanography of the New York Bight," by B. H. Ketchum, A. C. Redfield, and John C. Ayers, *Physical Oceanography and Meteorology*, Massachusetts Inst. of Technology, Cambridge, Mass., and the Oceanographic Inst., Woods Hole, Mass., Vol. XII, No. 1, 1951, p. 28.

observed that as the upper layer of the less saline water moves seaward it gets progressively more saline as additional sea water is transferred through the boundary. To provide this sea water there must be a flow in a landward direction. The purely empirical reasons for the reverse flow are more satisfactory than the description of pressure differentials. It should be possible to prove such a theory by a series of measurements of depth and the determination of the vertical and horizontal salinity gradients at and between carefully selected points.

Circulatory patterns such as described by the authors and the writer have been found in the coastal plain estuaries of the Atlantic coast and in some fiords. It is doubtful, however, whether the salt-wedge formations at the mouths of the Mississippi and Amazon rivers are strictly comparable to New York Harbor conditions. These rivers, with their tremendous outflow of fresh water, are cases in which the position of the salt wedge is entirely dependent on the river flow. It is doubtful whether any such well-defined salt wedge exists in New York Harbor. In the Hudson River, the position of the wedge would be influenced by, and probably dependent on, the tide.

It has been stated by the authors, that a wind of 30 miles per hr will induce a surface current—not in the direction of the wind—but about 20° to the right of the wind. Actually, V. W. Ekman found that surface currents caused by the wind were in a direction 45° to the right of the wind in the Northern Hemisphere and 45° to the left in the Southern Hemisphere.[18] This is true,

[18] "The Oceans," by H. V. Sverdrup, M. H. Johnson, and R. H. Flemming, Prentice-Hall, Inc., New York, N. Y., 1942.

however, only for an ocean of infinite depth, and Mr. Ekman found that near shore, the wind-driven current was much modified by the direction of the coast line. Depending on the angle between the coast line and the direction of the wind, the deviation of the current could vary from 0° to 53°. In shallow

water, the current flows in the direction of the stress at all depths. In all cases, the current is the resultant of several forces including the tidal current, the wind-driven current, and currents caused by river discharge and other nontidal drifts.

Abrupt changes in the barometric gradient in the vicinity of any estuary lead to surface oscillations having the characteristics of standing waves. These waves are long-period waves known as "seiches." The seiche superimposes another wave form upon that of the tide wave and gives the tide wave a "sawtooth" appearance. The seiche does not increase the mean range of the tide. Variations in sea level have been ascribed to variations in the average density of water columns as well as to other causes.[18]

Under the heading, "Tides and Sewage Disposal: Modified Theory of the Tidal Prism," the statement should be made: "Thus the low-tide volume of a given segment is equal to the high-tide volume of the adjacent landward segment." It should be noted that Mr. Ketchum postulates a net positive flow of fresh water seaward. In the case of a neutral estuary, Mr. Ketchum's theory would indicate no flushing. Where an inverse estuary exists, the flushing might be determined by assuming a negative inflow of fresh water. The deficiencies of the modified tidal-prism theory have been noted where stratification exists. Mr. Pritchard[11] has indicated that where the tidal wave has the features of a progressive wave, the successive estuary segments may have to be defined by means other than the average excursion of a particle of water on the flooding tide.

The waste-disposal capacities of many estuaries are limited by the extent of the chemical and biological changes acting within the estuary and the immediate, available dilution. When wastes are discharged at the head of the estuary, the tide has little influence on the actual effects produced by the waste or the natural processes of purification. Near the mouth of an estuary, where tidal effects are at a maximum, waste disposal can be considered as if the disposal were into the open ocean. Under some circumstances the sanitary engineer should ignore tidal "flushing" in computing the waste-receiving capacity of an estuary.

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WILLIAM T. INGRAM,[21] A.M. ASCE.—The writers are substantially in accord

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with Mr. Nusbaum's introductory statement that

> "* * * no part of the field of sanitary engineering applied to liquid-waste disposal has less applicable knowledge"

than the disposal of wastes in tidal waters. However, it is the very lack of this applicability and the widespread use of tidal waters as a receiver of liquid-borne waste materials that make the problem of tidal-waste disposal both challenging and valuable to sanitary engineers.

Mr. Nusbaum is to be commended for amplifying some aspects of the pertinent tidal phenomena. The matter of classifying estuaries in terms of the important factors that influence the mixing and movement of the water masses serves to emphasize the individual nature of estuaries. Because (under almost

all conditions) no single cause of movement and mixing predominates, it is doubtful that any system of classification, as such, can be of other than academic interest. In addition to the variation of tidal "flushing" characteristics and other estuarial phenomena between individual estuaries, emphasis should also be placed on the variation within a given harbor. This intra-estuarial variation applies not only to geographical variation, as discussed by Mr. Nusbaum, where

> "For example, in some estuaries the tidal motion will dominate near the channel connecting the estuary with the ocean, whereas well within the bay both wind and tide may contribute to the motion and the mixing"

but also to variations with time.

Certainly, at the same location in a harbor, radically different regimes have been observed between different seasons and even between successive weeks of the same season. At present (1953) the writers are engaged in a long-range study of pollution distributions in Upper New York Bay. For the same location, at a depth of 20 ft, there has been recorded—within the same year—a variation of (1) from less than 1.8 to 700 Most Probable Number of coliforms per milliliter; (2) from 7,630 ppm to 15,320 ppm of chlorides; and (3) from 28% to 88% of dissolved oxygen saturation. The site under discussion is half a mile from the shore and at least one mile from any major source of pollution.

Although intra-estuarial variation is implied in most studies which specify "flushing" times and other parameters (characterizing the distribution and detention of the water-borne wastes as a function of river flow and other factors), more emphasis should be placed on the effect of intra-estuarial variations. The over-all variation of estuarial characteristics both within and between estuaries is perhaps best summarized by paraphrasing the old adage to the effect that each harbor and even the components of a harbor are a law unto themselves. However, it was the original intent of the writers to outline those factors which can have an important influence on the movements of estuarial tidal-water masses and not to specify a quantitative description applicable to all estuaries. Both the original presentation and Mr. Nusbaum's discussion have realized this original intent and, by so doing, have indicated a more realistic approach to the appraisal of waste-disposal practices in estuarial waters.

DISCUSSION OF AN ANALYSIS OF WATER QUALITY CRITERIA
PROCEEDINGS-SEPARATE NO. 231

THOMAS R. CAMP,[1] M. ASCE.—The author's paper presents the philosophy of the new California Water Pollution Control Program which rules out the use of rigid standards and relies upon a case-by-case determination of whether pollution exists or threatens in each area. The writer cannot conceive of any rational and equitable control program which does not make use of water-quality standards. It is unrealistic to become involved in discussions as to whether the standards should be called "standards", "objectives" or "criteria". Whatever they are called, numerical criteria must be adopted as a starting point in any rational pollution-control program.

Any case-by-case determination of whether pollution exists in a given area will very soon reach a point where a definition of pollution is required. Any definition of pollution must be in terms of water-quality standards or criteria. Hence, California cannot avoid the use of quality standards. It may avoid the use of rigid standards and adapt the numerical figures to fit the needs of a particular area or a particular water use. This, of course, is what should be done.

It is the writer's opinion that both stream water-quality standards or criteria and effluent standards or limits must be used in any equitable abatement program. It is the duty of the pollution-control agency to establish the effluent standards in terms of limiting pollution loads at each point of pollution so that the water-quality standards for the stream will not be violated. Unless rational determinations are made for limiting pollution loads, the polluter has no means of knowing how much removal of pollutants must be accomplished. The polluters are entitled to a rational allocation of the pollution-receiving capacity of a stream. No individual polluter should be expected to attempt to make such an allocation because it would not have the force of law and it might interfere with the rights of other polluters.

All sewage and most liquid industrial wastes must eventually reach water courses in whole or in part. It is practicable only to reduce the quantity of polluting substances and to redistribute the points at which these substances are discharged. Since the objective of pollution abatement is to reclaim water courses for appropriate uses, the policy of pollution-control agencies should be directed to the maintenance of adequate water quality at least cost and not to the wholesale construction of treatment works. The policy should permit the selection of wastes to be treated for greatest overall economy and should permit some wastes to be discharged untreated if their treatment serves no useful purpose. Control agencies should establish limiting pollution loads allowable at each point of pollution and should reallocate loads when other riparian owners wish to produce liquid wastes.

The first step in a rational pollution-abatement policy is to establish the best highest use of a public water or portion thereof. This is known as stream classification according to use. Concurrent with this step is the establishment of water-quality standards or criteria for each use. This has already been done in many states. The next logical and necessary step is to study in the field each stream or public body of water to determine the points of

1. Partner, Camp, Dresser & McKee, Consulting Engineers, Boston.

pollution and the pollution-receiving capacity of the stream at each of the points. This step has been uniformly neglected throughout the country. It is absolutely necessary to any rational and equitable pollution-control program, but it has been ignored generally by the pollution-control agencies.

The process by which limiting pollution loads are established on any stream or stretch of stream will be accompanied by many difficult problems which nevertheless must be faced courageously. One of these problems is to determine for each stream or stretch of stream the particular stream flow to which the numerical standards are to apply. Obviously at higher rates of discharge the pollution-receiving capacity of the stream is not being fully utilized. It may, therefore, be necessary to permit excessive pollution for a small part of any one year. It may also be helpful to the polluter to permit storage of some of the pollutants during dry weather for release at times of high stream flow. Another problem which must be faced by the pollution-control agencies is that of overflows of mixed storm water and sanitary sewage during periods of rainfall. Any reasonable bacterial standards are sure to be violated during such periods where sewerage is on the combined plan. This problem must be faced by the control agencies.

It has now been about a decade since some of the states passed laws giving power to pollution-control agencies to abate pollution, and it has been five years since the passage of Public Law No. 845 giving some measure of control to the U. S. Public Health Service. The writer is of the opinion that the pollution-abatement movement is not progressing as fast as it should. The principal reason for the delay is the failure of the pollution-control agencies to follow through on particular streams so that the polluters may know what is required of them.

The profession and the public are indebted to the California State Water Pollution Control Board and particularly to Mr. Bacon and Dr. McKee for the bibliography entitled "Water Quality Criteria". This survey of the literature will be very helpful to control agencies in establishing standards for particular streams.

JOHN R. SNELL,[2] A.M. ASCE.–The subject of Water Quality Criteria is a controversial one and will likely remain so for at least several decades. The authors are to be congratulated for their explanation and defense of the California case-by-case determination of water pollution abatement as against the use of either rigid or guiding standards of a number of the Eastern States. Their literature review resulting in the publication "Water Quality Criteria" is also to be highly commended.

It should be kept in mind that the California experience is as yet very short (4 years) and also conditions in California vary from A to Z and would, therefore, not easily be covered by any statewide regulation. It is believed wise that California decentralize its primary stream control authority on a regional level, yet time may show several strong disadvantages of this decentralization as well as the case-by-case method of determining how much and what kind of pollution may be allowed. An industry wishing to become established may find itself delayed while a regional board debates its particular situation. One region may exercise rigid control and an adjoining region be extremely lenient. After another five years the situation may be reversed. Changes in process methods are sometimes frequent and radical and each time the industry may be delayed or thrown into confusion over inconsistent

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decisions or the whims of the board. The temptation is always present where the case-by-case method is employed to offer, or accept favors or bribes in consideration for preferred treatment.

It is believed that in states where conditions of seasonal water flow are much more constant than they are in many parts of California, it would be better to adapt a system of stream classification and pollution control based on a desired quality of the receiving waters. Standards of this type are, however, open to criticism and should be further studied and improved. The author's publication mentioned above "Water Quality Criteria" should be valuable in making such improvements. The concepts of self purification of streams has in recent years become better understood, dependable and adaptable to mathematical analysis. For example, in an extensive study of Banister Brook and the Sudbury River in Massachusetts, the writer was able to show a very close correlation between 6 months of weekly field data and a rigid mathematical analysis by both the "Streeter Method" and the newer "Thomas Method". The latter employing a third constant of sedimentation "K_3", although more complex to use, gives perhaps more consistently closer correlation with field data. When stream constants have been determined for various reaches, streams have been classified for desired quality and hydrological data analyzed to determine low stream flow conditions, the maximum quantities of the most common industrial wastes which may be discharged can be calculated and the condition of the stream predicted. This approach is one which has a great deal to commend it for a large portion of our country and should not be changed until considerable experience elsewhere proves that a superior approach has been developed.

E. W. STEEL,[3] M. ASCE. -- An adequate method of controlling stream quality should recognize the following facts.

1. A stream is an asset to the area in which it is located. Its possible uses include navigation, power, disposal of liquid wastes from cities and industries, agricultural and recreational use and as a source of water supply for cities and industries.
2. No nuisances should be allowed to develop.
3. The method used should be as simple and practical as possible and still attain its objectives.
4. The method should have the necessary flexibility to meet the changing conditions which affect stream pollution. These are the changes in regional development, seasonal changes, technical advances and any previously unforeseen factor.
5. The method should also be able to cope with differing situations, for example, the amount of waste discharged, its quality, and the amount of diluting water available.

Any control method proposed should be scrutinized as to its conformity with the above requirements.

Of the three methods discussed by the authors that of effluent standards is the simplest. It would seem that the standards would have to be of maximum quality unless the streams are zoned according to the uses made of them and the standards varied accordingly. Some degree of flexibility is possible by the changing of zones, but it is difficult to see how the fifth point mentioned above could be met.

3. Professor of Sanitary Engineering, The University of Texas, Austin, Tex.

The method of stream standards is less simple and more logical than that of effluent standards. Its principal drawback is its lack of compliance with Point Four. Exhaustive studies would be necessary in establishing the standards, their application to the various streams and whether a status quo is to be maintained for a stream, or portion of a stream, or whether its standard is to be raised. Continual studies and checks would also be necessary to check actual stream qualities throughout the state.

Instead of more or less frozen standards the authors recommend control by case-by-case study. The writer takes this to mean that in any case where nuisances are occurring or where any condition exists that is detrimental to substantial interests of an area that a study will be made and recommendations or orders will be given that will remedy matters. Similarly, proposed additional pollution would be forbidden, modified or allowed according to its effect upon the local conditions.

The case-by-case procedure provides the maximum of flexibility. Whether it requires more effort than use of stream standards is doubtful. If stream criteria for various uses are accepted and this is combined with the knowledge which the state health department or other pollution control agency can be expected to have, then additional special studies for any particular case would not appear to be especially burdensome.

The writer has had the opportunity of observing a modified case-by-case method in Texas. As elsewhere, stream pollution has been increased by the war and post-war lag in construction of sewage treatment plants and further aggravated by development of industries and increase in urban population. Yet the case-by-case method by steady but unspectacular progress is improving the streams. State law prohibits stream pollution, in terms almost as flat as that. Enforcement of the law is entrusted to the State Health Department and Fish, Game and Oyster Commission, and they receive the cooperation of the attorney general of the state.

According to the law every stream polluter should automatically be prosecuted by the enforcement agencies. This, however, would present difficulties for there is no practical definition in the law as to what constitutes pollution. Therefore, practical considerations rule, such as presence of nuisance or actual injury through interference with the uses mentioned under Point One. This, in effect, results in a case-by-case attack, even though the procedure is not authorized by law.

The law is difficult to enforce against cities. Injunctions are not practical, nor is the levying of fines or penalty of imprisonment against city officials, especially if the city is financially unable to make improvements to a sewage treatment plant. Yet, the constant pressure by the State finally brings the erring cities into line. This is done not by citing standards, which are not likely to be understood by city councils, but by citing the actual presence of nuisances or other injuries.

It has been advocated that the State Health Department be permitted by administrative act to set up stream pollution criteria that would simplify enforcement of the law. The reaction of industry to this is interesting. On the one hand it sees the advantage of a clarification of requirements that it must satisfy; on the other hand it fears that the regulating authorities may at some future time set up impractical standards. The result is that industry has lobbied against such revisions in the law. The motive, however, is not entirely fear. Industry has been satisfied with the way the problem has been handled in spite of the fact that where practical conditions have justified it the punitive measures of the law have been invoked against it.

Probably the most difficult problems arising in connection with stream pollution are not technical and administrative but financial, and occasionally legal. This is the case in Texas and undoubtedly in other states also. Cities and industries must have funds to construct treatment works, and this means delays and compromises no matter what the regulatory method is. This, of course, is another argument for a high degree of flexibility in regulation and for the case-by-case method.

Although hampered by lack of personnel, the regulating authorities in Texas have made the method work reasonably well. While there are areas in which pollution exists to an undesirable degree, conditions are improving. New sewage treatment works are related to local requirements, which, under most Texas conditions, call for a high degree of treatment. A similar policy is applied to industrial plants.

PROCEEDINGS-SEPARATES

VOLUME 80 (1954)

The technical papers published in the current calendar year are presented below. Technical division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering."

JANUARY: 379(SM),[a] 380(HY), 381(HY), 382(HY), 383(HY), 384(HY),[a] 385(SM), 386(SM), 387(EM), 388(SA), 389(SU),[a] 390(HY), 391(IR),[a] 392(SA), 393(SU), 394(AT), 395(SA),[a] 396(EM),[a] 397(ST).[a]

[a]Discussions grouped by Divisions.

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